Volatile losses from ammonium magnesium phosphate (struvite, $MgNH_4PO_4 \cdot 6H_2O$) under low pressures

*Matsumoto Yukako[1], Shogo Tachibana[1,2]

1. The University of Tokyo, 2. JAXA/ ISAS

Hydrated Mg phosphates are common phases in Bennu samples and show a characteristic cracked texture (e.g., Lauretta, Connolly et al., 2024; McCoy, Russel et al., 2025). Mg phosphates are also present in Ryugu samples (e.g., Nakamura et al., 2022; Nakato et al., 2022), where their amorphous nature suggests dehydration after formation (Ma et al., 2022). Hydrated Ammonium-Magnesium-Phosphorus (HAMP) -rich compounds, which show higher reflectance than the surrounding matrix and absorption bands corresponding to O-H, N-H, and P-O, have been identified in both Ryugu and Bennu samples (Pilorget et al., 2024, 2025). These Mg phosphates may have experienced volatile loss, and thus, they could record thermal histories on asteroid surfaces. To investigate the volatile loss behavior of ammonium Mg phosphate on asteroids, we performed heating experiments on struvite ($MgNH_4PO_4 \cdot 6H_2O$), a proposed original phase (Pilorget et al., 2024, 2025), under low pressures.
About 0.2 mg of powdered natural struvite (Niedersachsen, Germany) was kept at room temperature or heated at 40–300˚C under pressures of ˜200 Pa or 10^{-4}–10^{-5} Pa in vacuum furnaces (Matsumoto and Tachibana, 2026). The weight losses of the samples were used to quantify the volatile loss fraction. The starting materials and some of the run products were characterized by SEM (JEOL JCM-7000), FTIR (JASCO FT-IR 4200), and XRD (Rigaku MiniFlex600-C). In some experiments conducted under ˜10–4 Pa, released gas species were monitored using a quadrupole mass spectrometer (QMS, MKS Microvision2), connected to the furnace.

QMS analyses confirmed that water and ammonia were released from struvite. FTIR spectra showed decreases of absorption bands corresponding to H-N-H and O-H, which is consistent with QMS analyses. The run products kept at relatively low temperatures (e.g., 20 or 50˚C) showed infrared spectra that shared some characteristics with those of HAMPs in Ryugu and Bennu (Pilorget C. et al., 2024, 2025), for example, water absorption bands (at ˜3 μm and ˜6 μm) and NH_4 band (at ˜7 μm). XRD patterns of the run products showed only a broad peak, suggesting amorphization occurred as the degases proceeded. While the morphological change of struvite before and after heating was not observed, both the starting material and the run products exhibited cleavages that are similar to cracked textures seen in HAMP grains in asteroid samples, indicating that HAMPs in asteroid samples may have been crystalline in their precursor phase.

Under low pressures, degassing proceeded at lower temperatures than under 1-atm conditions (e.g., Frost et al., 2004). Even at room temperature (20˚C), about 70 wt% of the total volatiles (water and ammonia) in struvite was lost under ˜10^{-4} Pa. At temperatures below 300˚C, struvite was not completely degassed; instead, degassing stalled at a certain extent even with longer heating. The volatile loss fraction at which the reaction stalls increased with the heating temperature. A similar dehydration behavior under low pressures has also been observed for newberyite (Matsumoto and Tachibana, 2026).

This behavior is interpreted as reflecting the increasing activation energy for degassing caused by a decrease in the coordination number of Mg atoms as coordinated H_2O molecules and hydrogen-bonded NH_4^+ ions are removed (Matsumoto and Tachibana, 2026). In addition to this kinetic effect, we observed differences in degassing rates between low-vacuum and high-vacuum conditions. Slower volatile release under low vacuum suggests that the degassing of struvite may also be controlled by diffusion. Although further evaluation of the degassing mechanism is required, the reaction stalling at different volatile loss fractions depending on temperature suggests that residual volatile abundances in Mg phosphates of returned samples may constrain the thermal histories experienced by their parent bodies. Furthermore, the similarities between the FTIR spectra of run products at low temperature and reflectance spectra of HAMPs in asteroid samples imply that spectral characteristics may also serve as indicators of temperatures experienced by their host phases.

Keywords: Mg phosphate, Degassing, Ryugu, Bennu, Thermal history

